CLAIMS

I Claim:

1. A method of producing a wideband signal from a narrowband signal, the method comprising:

computing M_{nb} area coefficients from the narrowband signal;

interpolating the M_{nb} area coefficients into M_{wb} area coefficients;

generating a highband signal using the M_{wb} area coefficients; and

combining the highband signal with the narrowband signal interpolated to the highband sampling rate to form the wideband signal.

2. The method of claim 1, wherein computing M_{nb} area coefficients further comprises computing M_{nb} area coefficient using the following equation:

$$A_i = \frac{1+r_i}{1-r_i} A_{i+1}; \quad i = M_{nb}, M_{nb}-1, \ldots, 1,$$

where A_1 corresponds to a cross-section at the lips, $A_{M_{nb}+1}$ correspond to cross-sections of the vocal tract at the glottis opening and r_i are reflection coefficients.

3. The method of claim 1, wherein interpolating the M_{nb} area coefficients into M_{wb} area coefficients further comprises interpolating using a linear first order polynomial interpolation scheme.

4. The method of claim 1, wherein interpolating the M_{nb} area coefficients further comprises interpolating using a cubic spline interpolation scheme.

5. The method of claim 1, wherein interpolating the M_{nb} area coefficients further comprises interpolating using a fractal interpolation scheme.

6. The method of claim 1, further comprising:

insuring that the interpolated M_{wb} area coefficients are positive; and

setting $A^{wb}_{M_{wb}+1}$ to a finite positive fixed value.

7. The method of claim 1, wherein interpolating the M_{nb} area coefficients further comprises interpolating by a factor of 2, with a ¼ sampling interval shift.

8. A method of bandwidth extension of a narrowband signal, the method comprising:

computing M_{nb} log-area coefficients from the narrowband signal;

interpolating the M_{nb} log-area coefficients into M_{wb} log-area coefficients;

generating a highband signal using the interpolated M_{wb} log-area coefficients; and

combining the highband signal with the narrowband signal interpolated to the highband sampling rate to generate a wideband signal.

9. The method of claim 8, wherein computing M_{nb} log-area coefficients further comprises computing M_{nb} area coefficients using the equation below and computing their logarithmic values:

$$A_i = \frac{1+r_i}{1-r_i} A_{i+1}; \quad i = M_{nb}, M_{nb}-1, \ldots, 1,$$

where A_1 corresponds to a cross-section at the lips, $A_{M_{nb}+1}$ correspond to cross-sections of the vocal tract at the glottis opening and r_i are reflection coefficients.

10. The method of claim 8, wherein interpolating the M_{nb} log-area coefficients further comprises interpolating using a linear first order polynomial interpolation scheme.

11. The method of claim 8, wherein interpolating the M_{nb} log-area coefficients further comprises interpolating using a cubic spline interpolation scheme.

12. The method of claim 8, wherein interpolating the M_{nb} log-area coefficients further comprises interpolating using a fractal interpolation scheme.

13. The method of claim 8, wherein interpolating the M_{nb} log-area coefficients further comprises interpolating by a factor of 2, with a ¼ sample shift.

14. A method of extending the bandwidth of a narrowband signal, a preprocessing of the narrowband signal producing narrowband partial correlation coefficients (parcors), the method comprising:

(1) computing M_{nb} area coefficients from the narrowband parcors;

(2) computing M_{nb} log-area coefficients from the M_{nb} area coefficients;

(3) obtaining M_{wb} log-area coefficients from the M_{nb} log-area coefficients;

(4) computing M_{wb} area coefficients from the M_{wb} log-area coefficients;

(5) computing wideband parcors from the M_{wb} area coefficients;

(6) generating a highband signal using the wideband parcors; and

(7) combining the highband signal with the narrowband signal interpolated to the highband sampling rate.

15. The method of extending the bandwidth of a narrowband signal of claim 14, wherein obtaining M_{wb} log-area coefficients further comprises obtaining M_{nb} times two log-area coefficients using interpolation.

16. A method of producing a wideband signal from a narrowband signal, the method comprising:

(1) computing narrowband linear predictive coefficients (LPCs) from the narrowband signal;

(2) computing narrowband parcors r_i associated with the narrowband LPCs;

(3) computing M_{nb} area coefficients A_i^{nb}, $i = 1, 2,...,M_{nb}$ using the following: $A_i = \frac{1+r_i}{1-r_i} A_{i+1}; \quad i = M_{nb}, M_{nb}-1,...,1,$

where A_1 corresponds to a cross-section at lips, $A_{M_{nb}+1}$ and corresponds to a cross-section of a vocal tract at a glottis opening;

(4) extracting M_{wb} area coefficients from the M_{nb} area coefficients using interpolation;

(5) computing wideband parcors using the M_{wb} area coefficients according to the following:

$$r_i^{wb} = \frac{A_i^{wb} - A_{i+1}^{wb}}{A_i^{wb} + A_{i+1}^{wb}}, \quad i = 1,2,...,M_{wb};$$

(6) computing wideband LPCs a_i^{wb}, $i = 1,2,...,M_{wb}$, from the wideband parcors; and

(7) synthesizing a wideband signal y_{wb} using the wideband LPCs and an excitation signal.

17. The method of producing a wideband signal from a narrowband signal of claim 16, the method further comprising:

(8) highpass filtering the wideband signal y_{wb} to generate a highband signal; and

(9) combining the highband signal with the narrowband signal interpolated to the wideband sampling rate to produce a wideband signal $\hat{S}_{wb}$.

18. The method of producing a wideband signal from a narrowband signal of claim 16, wherein extracting M_{wb} area coefficients from the M_{nb} area coefficients using shifted-interpolation further comprises interpolating by a factor of 4 followed by a single sample shift and decimating by a factor of 2.

19. The method of producing a wideband signal from a narrowband signal of claim 16, the method further comprising:

(8) generating the excitation signal from a narrowband prediction residual signal using fullwave rectification.

20. The method of producing a wideband signal from a narrowband signal of claim 16, wherein M_{wb} equals two times M_{nb}.

21. The method of producing a wideband signal from a narrowband signal of claim 16, wherein extracting M_{wb} area coefficients from the M_{nb} area coefficients using shifted-interpolation further comprises interpolating by a factor of 2 with a ¼ sample shift.

22. The method of producing a wideband signal from a narrowband signal of claim 16, wherein extracting M_{wb} area coefficients from the M_{nb} area coefficients using shifted-interpolation further comprises using a first order linear shifted-interpolation.

23. The method of producing a wideband signal from a narrowband signal of claim 16, wherein extracting M_{wb} area coefficients from the M_{nb} area coefficients using shifted-interpolation further comprises using cubic-spline interpolation.

24. The method of producing a wideband signal from a narrowband signal of claim 16, wherein extracting M_{wb} area coefficients from the M_{nb} area coefficients using shifted-interpolation further comprises using fractal interpolation.

25. A method of extending the bandwidth of a narrowband signal, the method comprising:

(1) computing narrowband linear predictive coefficients (LPCs) from the narrowband signal;

(2) computing narrowband parcors associated with the narrowband LPCs;

(3) computing M_{nb} area coefficients using the narrowband parcors;

(4) extracting M_{wb} area coefficients from the M_{nb} area coefficients using shifted-interpolation;

(5) converting the M_{wb} area coefficients into wideband LPCs; and

(6) synthesizing a wideband signal y_{wb} using the wideband LPCs and an excitation signal.

26. The method of extending the bandwidth of a narrowband signal of claim 25, the method further comprising:

(7) highpass filtering the wideband signal y_{wb} to produce a highband signal; and

(8) combining the highband signal with the narrowband signal interpolated to the wideband sampling rate to produce a wideband signal $\hat{s}_{wb}$.

27. The method of extending the bandwidth of a narrowband signal of claim 25, wherein the step of converting the M_{wb} area coefficients into wideband LPCs further comprising computing wideband parcors from the M_{wb} area coefficients and using step-down back-recursion to compute the wideband LPCs.

28. The method of extending the bandwidth of a narrowband signal of claim 25, the method further comprising computing the excitation signal from a narrowband prediction residual signal.

29. The method of extending the bandwidth of a narrowband signal of claim 25, wherein the higher band of the excitation signal is highpass filtered white noise.

30. A method of extending the bandwidth of a narrowband signal, the method comprising:

(1) computing narrowband linear predictive coefficients (LPCs) from the narrowband signal;

(2) computing M_{nb} area coefficients using the narrowband LPCs;

(3) extracting M_{wb} area coefficients from the M_{nb} area coefficients using interpolation;

(4) converting the M_{wb} area coefficients into wideband LPCs; and

(5) synthesizing a wideband signal y_{wb} using the wideband LPCs and highpass filtered white noise in the higher band of an excitation signal and a linear prediction residual signal in the lower band of the excitation signal.

31. The method of extending the bandwidth of a narrowband signal of claim 30, wherein computing the excitation signal from a narrowband prediction residual signal further comprises inverse filtering the narrowband signal.

32. A method of producing a wideband signal from a narrowband signal, the method comprising:

(1) producing a wideband excitation signal from the narrowband signal;

(2) computing partial correlation coefficients r_i (parcors) from the narrowband signal;

(3) computing M_{nb} area coefficients according to the following equation:

$$A_i = \frac{1+r_i}{1-r_i} A_{i+1}; \quad i = M_{nb}, M_{nb}-1, \ldots, 1,$$

where A_1 corresponds to the cross-section at lips and $A_{M_{nb}+1}$ corresponds to the cross-section at a glottis opening;

(4) extracting M_{wb} area coefficients from the M_{nb} area coefficients using interpolation;

(5) computing wideband parcors r_i^{wb} from the interpolated M_{wb} area coefficients according to the following:

$$r_i^{wb} = \frac{A_i^{wb} - A_{i+1}^{wb}}{A_i^{wb} + A_{i+1}^{wb}}, \quad i = 1, 2, ..., M_{wb};$$

(6) computing wideband linear predictive coefficients (LPCs) a_i^{wb} from the wideband parcors r_i^{wb};

(7) synthesizing a wideband signal y_{wb} from the wideband LPCs a_i^{wb} and the wideband excitation signal;

(8) highpass filtering the wideband signal y_{wb} to produce a highband signal; and

(9) generating a wideband signal $\hat{s}_{wb}$ by summing the highband signal and the narrowband signal interpolated to the wideband sampling rate.

33. The method of producing a wideband signal from a narrowband signal of claim 32, wherein producing the wideband excitation signal from the narrowband signal further comprises:

performing linear prediction on the narrowband signal to find a_i^{wb} LP coefficients;

interpolating the narrowband signal to produce an upsampled narrowband signal;

producing a narrowband residual signal $\tilde{r}_{nb}$ by inverse filtering the upsampled interpolated narrowband signal using a transfer function associated with the a_i^{wb} LP coefficients; and

generating the wideband excitation signal from the narrowband residual signal $\tilde{r}_{nb}$.

34. A method of producing a wideband signal from a narrowband signal, the method receiving data associated with a narrowband signal, the method comprising:

(1) computing M_{nb} area coefficients using the narrowband data;

(2) extracting M_{wb} area coefficients from the M_{nb} area coefficients using interpolation; and

(3) synthesizing a wideband signal y_{wb} using wideband coefficients processed from data associated with the M_{nb} area coefficients and an excitation signal.

35. The method of producing a wideband signal from a narrowband signal of claim 34, the method further comprising:

(4) highpass filtering the wideband signal y_{wb} to form a highband signal; and

(5) generating a wideband signal $\hat{s}_{wb}$ by summing the highband signal and the narrowband signal interpolated to the wideband sampling rate.

36. A method of producing a wideband signal from a narrowband signal, the method comprising:

(1) computing M_{nb} area coefficients from the narrowband signal;

(2) computing M_{nb} log-area coefficients from the M_{nb} area coefficients;

(3) interpolating the M_{nb} log-area coefficients into M_{wb} log-area coefficients;

(4) converting the M_{wb} log-area coefficients into M_{wb} area coefficients; and

(5) synthesizing a wideband signal y_{wb} using the M_{wb} area coefficients and an excitation signal.

37. The method of producing a wideband signal from a narrowband signal of claim 36, the method further comprising:

(6) highpass filtering the wideband signal y_{wb} to produce a highband signal; and

(7) combining the highband signal with the narrowband signal interpolated to the wideband sampling rate to generate a wideband signal $\hat{s}_{wb}$.

38. The method of claim 36, wherein computing M_{nb} area coefficients further comprises computing M_{nb} area coefficients using the following equation:

$$A_i = \frac{1+r_i}{1-r_i} A_{i+1}; \quad i = M_{nb}, M_{nb}-1, \ldots, 1,$$

where A_1 corresponds to a cross-section at the lips, $A_{M_{nb}+1}$ corresponds to a cross-section at the glottis opening and r_i are reflection coefficients.

39. The method of claim 36, wherein interpolating the M_{nb} log-area coefficients into M_{wb} log-area coefficients further comprises interpolating using a linear first order polynomial interpolation scheme.

40. The method of claim 36, wherein interpolating the M_{nb} log-area coefficients further comprises interpolating using a cubic spline interpolation scheme.

41. The method of claim 36, wherein interpolating the M_{nb} log-area coefficients further comprises interpolating using a fractal interpolation scheme.

42. The method of claim 36, wherein interpolating the M_{nb} log-area coefficients further comprises interpolating by a factor of 2, with a ¼ sample shift.

43. The method of claim 36, wherein interpolating the M_{nb} log-area coefficients further comprises interpolating by a factor of 4 followed by a single sample shift and decimating by a factor of 2.

44 A method of generating a wideband signal from a narrowband signal, the method comprising:

(1) producing a wideband excitation signal from the narrowband signal;

(2) computing partial correlation coefficients r_i (parcors) from the narrowband signal;

(3) computing M_{nb} area coefficients according to the following equation:

$$A_i = \frac{1+r_i}{1-r_i} A_{i+1}; \quad i = M_{nb}, M_{nb}-1, \ldots, 1,$$

where A_1 corresponds to the cross-section at lips and $A_{M_{nb}+1}$ corresponds to the cross-section at a glottis opening;

(4) computing M_{nb} log-area coefficients by applying a log operator to the M_{nb} area coefficients;

(5) extracting M_{wb} log-area coefficients from the M_{nb} log-area coefficients using shifted-interpolation;

(6) converting the M_{wb} log-area coefficients into M_{wb} area coefficients;

(7) computing wideband parcors r_i^{wb} from the M_{wb} area coefficients according to the following:

$$r_i^{wb} = \frac{A_i^{wb} - A_{i+1}^{wb}}{A_i^{wb} + A_{i+1}^{wb}}, \quad i = 1, 2, \ldots, M_{wb};$$

(8) computing wideband linear predictive coefficients (LPCs) a_i^{wb} from the wideband parcors r_i^{wb}; and

(9) synthesizing a wideband signal y_{wb} from the wideband LPCs a_i^{wb} and the wideband excitation signal.

45. The method of generating an output wideband signal from a narrowband signal of claim 44, the method further comprising:

(10) highpass filtering the wideband signal y_{wb} to generate a highband signal S_{hb}; and

(11) generating a wideband signal $\hat{s}_{wb}$ by summing the highband signal S_{hb} and the narrowband signal interpolated to the wideband sampling rate.

46. The method of generating a wideband signal from a narrowband signal of claim 44, wherein producing a wideband excitation signal from the narrowband signal further comprises:

performing linear prediction on the narrowband signal to find a_i^{wb} LP coefficients;

interpolating the narrowband signal to produce an upsampled interpolated narrowband signal;

producing a narrowband residual signal $\tilde{r}_{nb}$ by inverse filtering the upsampled interpolated narrowband signal using a transfer function associated with the a_i^{wb} LP coefficients; and

generating a wideband excitation signal from the narrowband residual signal $\tilde{r}_{nb}$.

47. A method of producing a wideband signal from a narrowband signal, the method comprising:

computing M_{nb} area coefficients from the narrowband signal;

interpolating the M_{nb} area coefficients into M_{wb} area coefficients; and

generating the wideband signal using the M_{wb} area coefficients.

48. The method of generating a wideband signal from a narrowband signal of claim 47, wherein interpolating the M_{nb} area coefficients further comprises interpolating by a factor of 4 followed by a single sampling interval shift and decimating by a factor of 2.

49. A method of producing a wideband signal from a narrowband signal, the method comprising:

computing M_{nb} log-area coefficients by applying a log operator to M_{nb} area coefficients generated from the narrowband signal;

extracting M_{wb} log-area coefficients from the M_{nb} log-area coefficients using interpolation; and

generating a wideband signal using M_{wb} area coefficients generated from the M_{wb} log-area coefficients.

50. The method of generating a wideband signal from a narrowband signal of claim 49, wherein extracting the M_{nb} log-area coefficients using interpolation further comprises interpolating by a factor of 4 followed by a single sampling interval shift and decimating by a factor of 2.